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Sediment Deposition in an Attic Near a Region of Dust Provenance: Implications for Historic Regional Dust Dispersion and Deposition Patterns

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Introduction

Fugitive dust is a frequent product of wind erosion and is often the most visible evidence of wind erosion downwind from actively eroding fields. While wind erosion may occur on any soil surface, it is most prevalent in semi-arid climates. Fugitive dust negatively impacts human activity and the environment and, while it has long been recognized that dust is a human health concern, only recently has the environmental cost associated with the dust-borne transport of plant nutrients (Zobeck and Fryrear, 1986), soluble and chelatable metallic salts (Prospero, 1999), and pesticides (Larney et al., 1999) been considered. These contaminants affect human health when they are transported over population centers (Prospero, 1999) and impact the nutrient loading of waters flowing from adjacent watersheds (Wood and Sanford, 1995).

Recent advances in weather data availability, satellite imagery, geographical information systems (GIS), and computer modeling have made it possible to predict, measure, and track plumes of dust emanating from selected source regions (Saxton et al., 2000). The particle size distribution of soil-derived dust most closely approximates a two parameter Weibull function (Zobeck et al., 1999). With increasing distance and time in transport, the larger particles with higher terminal velocities settle out of the airmass leaving progressively finer and finer particles in suspension.

A large body of data exists on the physical and chemical properties of soil-derived dust. Elemental and mineralogical analyses have been used to identify the source regions of dust deposited in Arctic ice caps and other depositional surfaces. More recently, biological fingerprinting has been used to more closely match mineral aerosols with the soil from which they were winnowed. While current technology is allowing characterization of atmospheric dust, little information is available concerning recent historic trends in dust transport and the physical, chemical, and microbiological characteristics of that dust.

Dust deposited in attics has recently been used to explore the history of aerosol contaminants in a given locality. Cidziel and Hodge (2000) collected dust from several attics in southern Nevada and Utah and analyzed the dust for trace elements and pesticides. Attics provide an ideal location for archived dust because they are rarely cleaned and the dust that settles in them is protected from rain and ultraviolet radiation. Attics typically have very small vents in relation to the total cross section and very small velocities of air movement with little turbulence. In such a system we hypothesized that the particles would settle in a very short distance compared to the regional pattern in the windy and turbulent conditions often associated with dust generation. Such a system should provide a physical scale model of the deposition basin for a dust source area. Our study was undertaken to investigate the properties of dust sampled in attic built in 1954 and to determine whether the chemical, physical, and microbiological characteristics of dust deposited at different locations in the same attic might be representative of regional patterns.

Methods

Big Spring, Texas is located at 32^o 15' north latitude 101^o 30' west longitude near the southern terminus of the Southern High Plains, a locally important source region for dust generation. Approximately one half of the surrounding land is utilized for dryland production of summer crops including cotton and grain sorghum. During the winter and spring, the fields are fallowed and susceptible to erosion by the often gusty winds that blow predominantly from the west and southwest from January through May.

Very near the center of Big Spring, a rectangular two story building was added to an existing church structure in 1954. The long axis of the building is oriented approximately into the direction of the winds that prevail during the erosion season. The attic is ventilated with a small louvered vent at the top of the gable approximately 8 m above the ground on the upwind side and by a louvered bell tower on the downwind side. Dust samples were collected from a measured area approximately 0.4 m downwind (toward the center of the attic) from the vent and at 1.1 m intervals up to the center of the building. A total of 13 samples varying from 5.9 to 81.9 g each were collected. The samples were placed in pre-weighed soil cans, labeled, dried in an oven at 60^o C for 48 hours. The samples were then passed through a 60 mesh (250 µm) screen to remove building debris and macrobiological materials and weighed to the nearest 0.001 g.

Total dust deposition, expressed as kg m^{-2}, was calculated for each sample and particle size analysis was performed on 0.3 g dust samples diluted in a sodium hexametaphosphate solution and sonically dispersed on a Beckman-Coulter LS230 laser/PID particle size analyzer. Percentages of organic carbon and total nitrogen were determined with an Elementar C/N analyzer. Although results are not presently available, additional chemical analyses including trace metal contents and $^{239+240}$Pu content are currently underway.

Total dust deposition, particle size analysis, percent N, and percent organic C data were regressed as a function of distance from the upwind vent using a simple exponential decay function of the form:

$$y = a\,(e)^{-(x/b)} \qquad (1)$$

where a is a scaling factor and b is a shape factor. The location 1.5 m from the vent was excluded from the fit for total deposition due to evidence of surface replacement after the date of construction.

Results

The total dust deposition, mean particle diameter, median particle diameter, modal particle diameter, 5th and 95th percentile particle diameters (d_5 and d_{95}, respectively), percent nitrogen (N), and percent organic carbon (C) are presented for each sample in Table 1along with the fitted a and b parameters and coefficients of determination for Eq. 1. All measures were highly correlated with distance from the vent with the exception of percent N. The appearance of sand-sized particles in the locations within 3 m of the vent that is located 8 m above the ground at a distance of 4 km from the nearest farm field is evidence of the height of large particle entrainment possible in the turbulent, fast moving dust storms that frequent the Big Spring area. The total dust deposition drops very rapidly from the point of entry at the attic vent. The exponential decay curve for total deposition was much more eccentric than for the other physical

Table 1. Measures of physical and preliminary chemical attributes of the attic dust samples

Distance (m)	Deposition kg m^{-2}	Mean d µm	Median d µm	Modal d µm	d_5 µm	d_{95} µm	Percent N	Percent C
0.4	1.0009	48.5	35.4	55.1	1.1	133.7	0.14	3.18
1.5	*0.5560	42.0	28.2	50.2	1.1	111.0	0.25	3.51
2.6	0.6082	39.1	28.1	50.2	1.0	101.1	0.15	3.43
3.7	0.4632	35.5	22.1	41.7	1.0	96.6	0.19	4.31
4.8	0.3499	32.7	19.1	38.0	1.0	89.4	0.18	4.42
5.9	0.2487	29.7	17.5	38.0	0.9	89.4	0.13	5.56
7.0	0.1872	31.5	17.0	34.6	0.9	93.9	0.13	5.72
8.1	0.1623	24.4	15.0	25.3	0.9	76.4	0.11	5.92
9.2	0.1077	24.1	13.7	20.7	0.9	77.7	0.18	6.26
10.3	0.0956	23.2	12.7	19.8	0.8	76.4	0.12	6.87
11.4	0.0759	21.9	11.8	19.5	0.8	71.9	0.12	7.48
12.5	0.0738	20.4	11.0	18.0	0.8	69.6	0.14	7.52
13.6	0.0764	20.4	11.3	18.0	0.8	68.6	0.12	7.95
a (Eq. 1)	1.107	47.292	34.287	59.610	1.053	121.676	0.189	3.351
b (Eq. 1)	4.170	14.307	10.101	10.523	46.059	20.966	29.238	-14.916
r^2 (Eq. 1)	0.997	0.969	0.961	0.962	0.938	0.891	0.319	0.964

* Identified as an outlier and excluded from curve fit due to evidence of surface replacement after1954

factors as evidenced by the relatively small value for the fitted shape parameter, b. This phenomenon may be attributed to several factors including the rapid settling of the larger particles upon entry to the relatively still attic. Particle momentum would drop rapidly upon entry and fast moving large particles entering the attic space would rapidly slow to the attic velocity and settle very close to the vent. Finally, days with little wind and atmospheric dust would result in attic airmass velocities very near zero and particles settling close to the vent.

Particle size distributions for all locations were skewed toward the larger particles. The d_{95} for the 3 locations nearest the vent is in the fine sand range. At the 3.7 m location, the d_{95} is in the very fine sand range and at no location was there an absence of very fine sand. This finding indicates that the airmass velocity is not constant across the attic cross section as the 3 m height of the attic and the approximately 0.4 m s^{-1} terminal velocity of a 69 µm particle would require a maximum transport time of less than 7.5 s and an attic airmass velocity of nearly 2 m s^{-1}in order for that particle to reach the 13.6 m location. Assuming a 1% vent opportunity area, this would require a highly improbable 200 m s-1 wind speed outside of the attic. Samples were collected very near the centerline of the attic and locations away from this centerline probably have smaller d_{95} than those observed.

The d_5 of the particle size distributions did not vary as much as the d_{95}. The particle size analysis was performed on dispersed samples and thus any particle coatings or micro-aggregates would be recorded as clays. It is probable that particle size analysis with non-dispersed samples in a media with a very low dielectric constant would reveal a higher actual d_5 for the samples. The close range of the sample d_5 and wide range in d_{95} resulted in an increasingly narrow particle size distribution with increasing distance from the vent. This phenomenon is consistent with patterns observed in regional dispersion and deposition.

The percent organic C increased with increasing distance from the vent. This phenomenon may be explained by the physical behavior of the two forms of organic C. The structured forms of organic C often have irregular shapes, lower densities, and lower terminal velocities than mineral particles of similar size. Humic forms of organic C are usually found as surface coatings and finer particles with higher surface area to volume ratios have higher percentages of humic C

It is unclear why there was no observed correlation of N with distance from the vent except to note that soil N in surrounding soils is very low and the addition of nitrogenous foreign materials such as the proteins in small plant detritus, small insect body parts, and animal waste products not sieved from the samples may have eclipsed any differences arriving and sorting with the mineral portion of the samples. Analysis of bulk dust samples collected in an adjacent attic built in 1930 had lower N percentages than those collected in this 1954 addition. Local farmers greatly increased the use of nitrogen fertilizers during the 1950s and the increased surface soil N levels are apparently expressed in the percentage N of the fugitive dust transported from the fields.

Conclusions

The exponential decay of total deposition and particle sizes with increased distance and time of transport is consistent with patterns noted in regional dust dispersion and transport. It would appear that this and other attics may offer scale physical models of regional dust dispersion and deposition that will allow relatively undisturbed sample collection to determine the physical and chemical nature of dust that has been transported over and deposited in nearby population centers and watersheds in recent history.

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